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LANGUAGE CHANGE IN SOCIALLY STRUCTURED POPULATIONS

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Language contact is a significant external social factor that impacts on the change in natural languages over time. In some circumstances this corresponds to language competition, in which individuals in a population choose one language over another based on their social interactions. We investigated the dynamics of language change in two initially separate populations of agents that were then mixed with levels of influence determined by the social classes of the two populations, with 16 different combinations tested. As expected, the study found that how the communities interact with each other impacts on the communal language developed. However, it was also found that the acquisition of new words was substantial even with limited interaction between populations and low levels of influence, and that comprehension could be well established across language groups even when production of words from the other language group was low.

1. Introduction

Language changes over time as individuals learn from their peers and from previous generations. All natural languages change, through drift, dialect interference, and foreign interference (Thomason & Kaufman, 1988). Language change may be influenced by external sociolinguistic and internal psycholinguistic factors (Aitchison, 1991). When populations are isolated, languages undergo independent evolution, leading to the formation of dissimilar languages. When populations interact, language contact is an external factor that frequently results in language change, often through the borrowing of words (Thomason, 2001). In situations where a community has no shared language a pidgin may emerge, taking elements from the existing languages of individuals in the community (Aitchison, 1991). Social factors affect the extent of language change in a contact situation, with more prestigious languages less likely to change than less prestigious ones (McMahon, 1994).

Competition between languages has been studied using parameterized models speaking one of two possible languages (Abrams & Strogatz, 2003), with extensions allowing bilingualism (Castello, et al., 2008) and considering population densities (Patriarca & Leppänen, 2004). Simple models of language competition predict that two languages cannot co-exist stably, with one eventually driven to extinction (Abrams & Strogatz, 2003; Castello, et al., 2008). Other models represent languages as bit-strings, allowing individuals to learn aspects of languages and enabling language elements to remain even when the species that used the language is driven to extinction (Kosmidis, Halley, & Argyrakis, 2005). The degree of contact between multiple populations affects the convergence of a communal language (Gong, Minett, & Wang, 2008).

Another type of model for investigating language evolution is agent-based modeling, including language games (Steels, 1995) and iterated learning (Kirby & Hurford, 2002). Agent-based models allow populations of agents to develop shared lexicons with meaningful referents and enable investigations into changes in meaning and word use over time. The variability of agent interactions and the asymmetry of some social structures are best modeled with agents, rather than by modeling field effects. Our previous work on language change demonstrated that a range of factors influence how language changes over generations of agents, including the period of individual language learning, concept formation methods, and the social interactions (Schulz, Wyeth, & Wiles, 2010).

Social interactions between agents have been specified by the social networks of individuals, comparing regular, small world, and community structured networks (Castello, et al., 2008), finding different times to extinction for languages in competition. Another model of differential social interactions implemented a theory of influence based on popularity, derived from social impact theory (Nettle, 1999). Measures of popularity have been used to weight the influence of an individual on others' language updates and to determine the probability of an individual participating in an interaction (Gong, 2010). Popularity was found to impact on the speed of categorization and whether new words would spread through a population.

In this paper, we introduce a new component into models of influence, in which we deliberately separate influence from frequency in the language learning processes. We chose to implement an agent-based model of language with two populations of agents, and to study the impact of differential social interactions on the lexicons of agents in the populations. This project extends our earlier work on the Lingodroid project (Schulz, Wyeth, & Wiles, 2011) by introducing a social-class structure to the agent interactions. The Lingodroids are agents that explore a spatial environment and interact socially to construct shared lexicons for spatial concepts. The use of populations of agents with spatial representations results in evolved languages in which lexicons and semantics can be compared in detail between language learners, enabling analyses which would not be possible for more abstract methods for representing languages.

2. Methods

Agents were designed to interact socially to form concepts and lexicons for place names (called *toponyms*), distances, and directions (Schulz, Glover, Milford, Wyeth, & Wiles, 2011; Schulz, Wyeth, et al., 2011). A grid world was used to provide a simple spatial environment for the agents to move and interact in.

2.1. *Agent Interactions*

The agents interacted through three types of conversations. Through *where-are-we* conversations, agents created a shared lexicon for toponyms to describe locations in the world. Using the toponym lexicon, agents then created a shared lexicon for distances through *how-far* conversations and for directions through *what-direction* conversations. In a conversation:

1. Two agents were randomly chosen from the population of agents, one as the speaker and the other as the hearer;
2. Topic selection occurred, with different methods used:
    a. In a *where-are-we* conversation, the speaker was placed in one of the grid squares, the hearer was placed close by in one of the grid squares within a 2 square neighbourhood of the speaker's location, and the hearer requested that the speaker name the current location;
    b. In a *how-far* conversation, the hearer randomly chose two toponyms from its lexicon (possibly the same word) and requested that the speaker name the distance between the specified toponyms;
    c. In a *what-direction* conversation, the hearer randomly chose two different toponyms from its lexicon and requested that the speaker name the direction from 'North' to the first of the specified toponyms when located at the second toponym;
3. The speaker produced an utterance to describe the topic;
4. Both agents updated their lexicons.
5. Failure: The interaction ended in failure if the speaker did not understand the toponyms specified in a *how-far* or *what-direction* conversation, or if the speaker did not have or invent a word to describe the topic.

If the hearer did not know the word used by the speaker, the word was added to its lexicon. The process of updating lexicons depended on the agents' classes and the interaction type (see the next section for details).

2.2. *Lexicon Construction*

Agents stored the associations between words and component parts of concepts, called *concept elements*, in three distributed lexicon tables (Schulz, Wyeth, et al., 2011), one each for toponyms, distances, and directions. The concept elements for toponyms were grid squares. Concept elements for distances and directions were created as the agents experienced new distances and directions in *how-far* and *what-direction* interactions. The association, a_{ij}, between a concept element, *i*, and a word, *j*, was updated as follows:

$$a_{ij} \leftarrow a_{ij} + q \tag{1}$$

where *q* was the influence determined by the classes of the speaker and the current agent. When the classes of the speaker and the current agent were the same (including when the speaker was the current agent), *q* was equal to 1. When the classes of the speaker and the current agent were different, *q* was equal to the influence associated with the speaker's class by the current agent, a value between 0 and 1. For a mixed population with two classes, a single value was specified for each class, with *q1* determining the influence class 2 has on class 1, and *q2* determining the influence class 1 has on class 2.

In each interaction, the speaker produced an utterance to name the concept element, *i*, by calculating the confidence value, h_{ij}, for each word, *j,* as follows:

$$h_{ij} = \sum_{k=1}^{X} \frac{a_{kj}(D - d_{ki})}{D} \Big/ \sum_{m=1}^{N} c_{mj} \tag{2}$$

where a_{kj} was the stored association between the concept element, *k*, and the word, *j*; d_{ki} was the distance between the concept elements *k* and *i*; c_{mj} was the count of the number of times the word, *j*, had been used together with the concept element, *m*; *X* was the number of concept elements within a neighborhood D, of concept element *i*; and *N* was the total number of concept elements. Words were invented with probability, *p*, as follows:

$$p = \begin{cases} 0.05 & \text{if } \mathrm{h_{ij}} = 0 \\ k\exp(-h_{ij}/((1-h_{ij})T) & \text{otherwise} \end{cases} \tag{3}$$

where *k*=1, h_{ij} was the confidence value of the concept element-word pair, and *T* was the temperature, setting the word invention rate.

The key difference from previous Lingodroid studies was that associations between words and concepts were separated from word-use frequency to allow influence to differentially affect confidence values.

2.3. *Performance Measures*

Two performance measures were used to analyze the resulting lexicons: production coherence and comprehension coherence. Production coherence was calculated per lexicon over a set of concept elements: the squares of the grid for toponyms, every 0.5 squares for distances, and every 10° for angles. Production coherence was scaled between 0 and 100%, with higher values indicating that the robots produced similar words for similar concept elements (for details, see Schulz, Wyeth, et al., 2011). Comprehension coherence for a word was calculated as the average distance between the location, distance, or direction chosen by each agent in the population for that word. The comprehension coherence of a lexicon was the average comprehension coherence of all words in the lexicon. Comprehension coherence for locations and distances was measured in squares (meters), and for directions in degrees, with lower values indicating that words in the lexicon were interpreted similarly across the population.

3. Study Design

Initially, two separate populations of eight agents negotiated toponym, distance, and direction lexicons through 28,000 interactions of each type (*where-are-we*, *how-far*, and *what-direction*). The two populations were then combined, with one population set to class 1 and the second set to class 2. The combined population further negotiated their lexicons through 2000 interactions of each type. The agents used a neighborhood size of two squares (meters) for locations and distances and 30° for directions; the size of the grid world was 15 squares by 15 squares; and the word invention temperature was 0.02. Each population was assigned one of four possible social classes, which affected the lexical updating processes of its own and the other population. The study formed a 4x4 design with the influence values $q1$ and $q2$ set to 0, 1/3, 2/3, or 1. Each of the sixteen conditions produced one shared language. The resulting languages were analyzed for diversity and coherence in production and comprehension.

4. Results

The initial lexicons of the agents contained 44 and 62 toponyms (with production and comprehension coherences of 73.7% and 1.61m, and 67.8% and 1.56m), 8 and 10 distance words (78.7% and 0.31m, and 68.9% and 0.62m) and five and four direction words (95.2% and 58.0°, and 80.0% and 45.3°). The final lexicon sizes were either the same as the initial values, when the influence of the other class was equal to 0, or had increased to 71–102 toponyms, 17–19 distance words, and 9 direction words. Words acquired from the other class were not well established, as indicated by lower coherence values (see Figure 2) and by the agents' lexicons (see Figure 1).

As expected, production coherence within each class decreased as the influence of the other class increased for all three lexicons (as *q* increased from 0 to 1, toponym coherence decreased from 70.8% to 40.7%, distance coherence decreased from 72.4% to 50.4%, and direction coherence decreased from 87.0% to 66.1%). However, there was no correlation between comprehension coherence and influence. For toponyms, within-class coherence remained between 1.59m and 1.63m, and between-class coherence varied between 2.40m and 2.63m, with similar results obtained for distances and directions. The interaction between influence and the resulting lexicons can be clearly seen in the toponyms chosen, and the distance and direction templates used to choose words (see Figure 1).

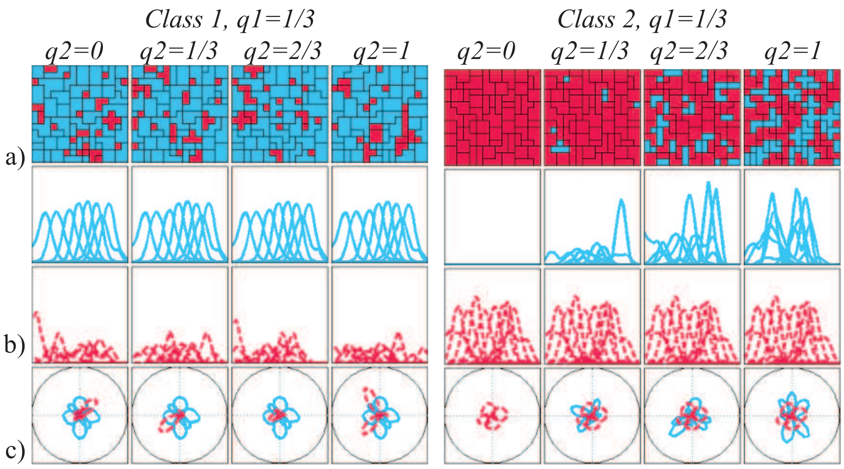

Figure 1 Lexicons for $q1$=1/3 and $q2$=0, 1/3, 2/3, and 1. Each column shows the lexicons of a single agent at the end of the mixed interactions. The color of each word indicates the original class that used the word, with light blue for class 1 and dashed red for class 2. a) In the toponym lexicons, boundaries between toponyms are indicated with black lines. Across all $q2$ values, the class 1 agent has used some class 2 toponyms, depending on the specific interactions of the agent. As the influence of class 1 increased from $q2$=0 to $q2$=1 the number of class 1 toponyms used by the class 2 agent increased. b) Distance templates show the confidence for each word from 0 to 1 (y-axis) over distances from 0m to 20m (x-axis), separated into class 1 words (top row) and class 2 words (bottom row). For the class 2 agent, as $q2$ increased, the templates for class 2 words remained similar to the initial templates and the confidence in class 1 words increased. c) Direction templates show the confidence of each word from 0° to 360°, with 'North' pointing towards the top of the page. The circle corresponds to a confidence value of 1. The interplay between class 1 and class 2 words can be seen at all levels of influence. If a word from the other class corresponded to a concept that was not confidently associated with a word, then this word gained popularity in both classes.

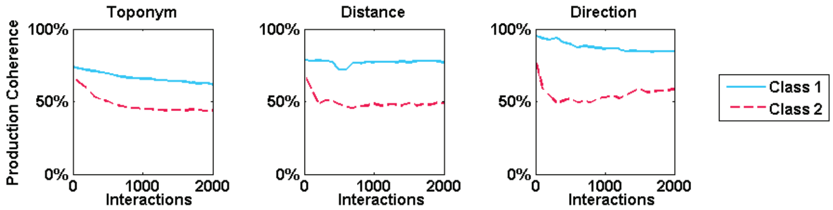

Figure 2 Production coherence for the toponym (left), distance (middle), and direction (right) lexicons for both classes throughout the mixed interactions for $q1$=1/3 and $q2$=1. Production coherence for class 2 decreased for all lexicons as many of the class 1 words were used by class 2 agents (from 67.8% to 43.8% for toponyms, from 59.4% to 48.7% for distances, and from 80.6% to 58.3% for directions). For class 1, production coherence was more stable (from 73.7% to 61.7% for toponyms, from 93.7% to 84.1% for distances, and from 74.4% to 77.0% for directions), as the words chosen by class 1 agents predominantly remained the same.

5. Discussion

The study presented in this paper has shown that differential social interactions impact on the communal language developed by two initially separate populations of agents, in particular how quickly words are acquired and how well established they become. While words are acquired quickly with both low and high influence, high influence allows words to become well established in the population sooner. These results are consistent with the findings from previous studies on language competition, in which communal languages develop (Gong, et al., 2008) or one language is driven to extinction but has contributed words to the remaining language (Kosmidis, et al., 2005). However, the results also show that the acquisition of new words can be substantial with small numbers of interactions and small amounts of influence. In particular, while agents may not choose to use the words of another class, comprehension may be well established.

Language contact and competition have a significant impact on changes in natural languages (Thomason & Kaufman, 1988). Situations in which language contact occurs include different social classes, trade, invasion, and a multicultural society. The spatial language change model presented in this paper has shown that brief contacts between populations with low influence may result in individuals acquiring significant numbers of words.

Our model of language learning incorporating social status intentionally separated influence from word frequency. We have proposed one mechanism to achieve this separation, with interesting consequences for word production and comprehension. The methodology could be extended from influence between groups to social structure within a group. Further research could determine whether this mechanism is necessary or sufficient, and the extent to which the model corresponds to the influence that human social structures have on vocabulary learning in multilingual situations.

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